Simulating On-Board Compression with JPEG 2000

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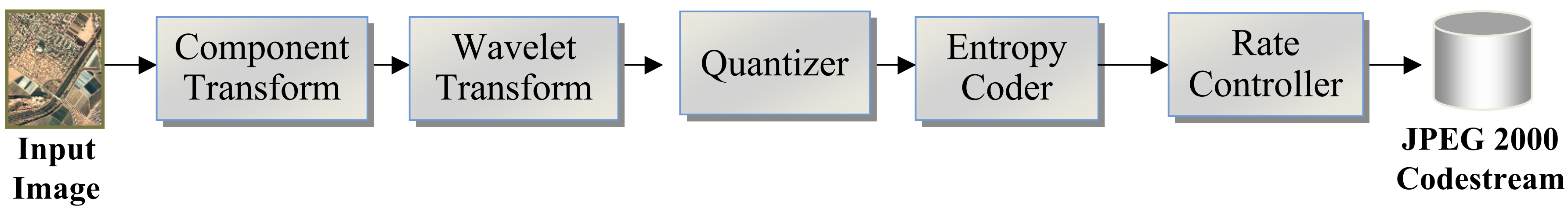
Objectives of the Project

- Optimize JPEG 2000 Verification Model (VM) for Earth Science Applications
  - Incorporate Part 2 features in Scan-Based Mode
- Test in Laboratory Environment
- Port to “Relevant” Environment
  - Test in that Environment
- Contribute to Standardization Process

JPEG 2000 Algorithm



JPEG 2000 Part 1 and Part 2

- Part 1: Core Coding System
  - Two wavelet filters (one reversible, one irreversible)
  - Scalar quantization (SQ)
  - Limited color space transforms
- Part 2: Extensions
  - User-selectable wavelets
  - Trellis-coded quantization (TCQ)
  - User-selectable transform in component (wavelength) dimension
  - Other refinements

The Scan-Based Mode of JPEG 2000

- Low-memory Implementation for Use on Board Spacecraft
  - Buffers minimum number of image lines
  - Outputs directly to codestream for downlink
- Processes Image as a Series of “Scan Elements”
  - Each scan element corresponds to 8 to 64 lines in image space
  - Scan elements may be tiles or precincts (tiles in wavelet domain)

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TRADES

- TRADES: Toolkit for Remote-Sensing Analysis, Design, Evaluation, and Simulation
  - Developed by Ball Aerospace
  - Supports simulation and analysis in any spectral regime (UV through passive microwave)
  - Supports most scene sampling designs: whiskbroom, pushbroom, conical, step-stare scans
  - Supports many sensor types: panchromatic, filter multispectral, grating hyperspectral
  - Includes all functions required for simulation

TRADES (continued)

- Provides physically accurate simulation of a remote sensing system (space-based or aircraft)
  - Viewpoint: Establishes viewing geometry
  - Radiance: Adds illumination and atmospheric scattering
  - Imaging: Optics and line-of-sight disturbances
  - Detection: Adds noise and readout electronics effects
  - Calibration: Simulates on-orbit or ground calibration
  - Format: Spectral or spatial binning

Technical Status

- Completed experiment on compression of uncalibrated panchromatic and multispectral data
- Began error resilience experiment by simulating complete loss of one data packet
- Initiated task-oriented experiments with two science user groups

Calibration Experiment

- Panchromatic data
  - High-resolution aerial photograph used to simulate lower resolution image from a satellite-borne scanner
  - Image extracted from TRADES before calibration and compressed (Pre/Cal)
  - Decompressed image then calibrated as usual
  - Result compared with compression after “on-board” calibration (Post/Cal)
- Multispectral data
  - High spectral and spatial resolution image (AVIRIS) used to simulate Landsat bands and resolution
  - (Pre/Cal) and (Post/Cal) data produced as for panchromatic data

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Original Panchromatic Image

Uncalibrated

Calibrated

Panchromatic Image at 2.0 bpp

Pre/Cal

Post/Cal

Panchromatic Image at 0.125 bpp

Pre/Cal

Post/Cal

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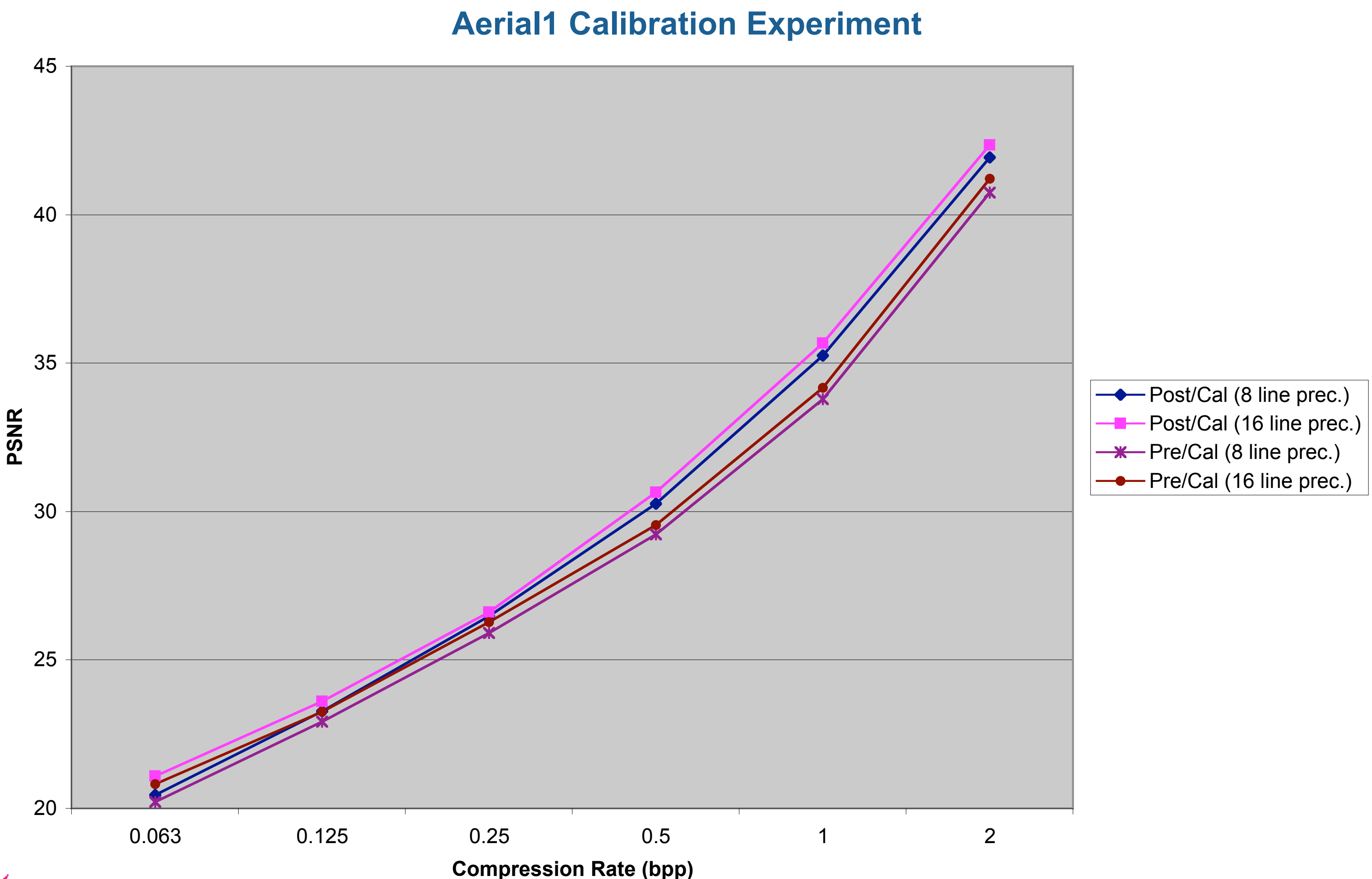
PSNR for Panchromatic Image



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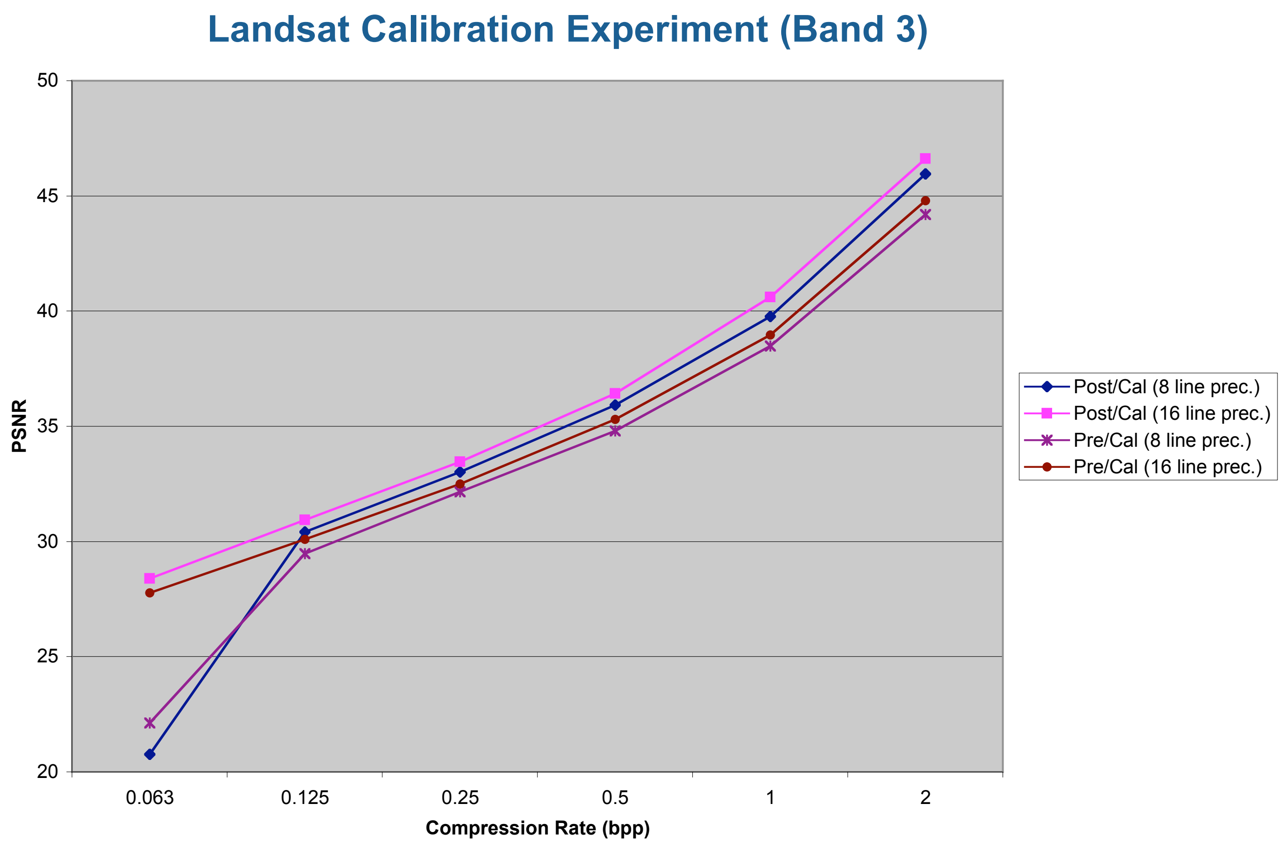
PSNR for Multispectral Image

Synthesized Image
Bands 4, 3, 2



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Conclusions on Calibration

- On-board calibration (Post/Cal) always produces slightly better PSNR
  - Difference is small except at lowest bit rates
- No visual difference between on-board (Post/Cal) and on-ground (Pre/Cal) calibration at highest bit rates
- At lowest bit rates, on-ground calibration may actually introduce objectionable streaking
  - No calibration at all might be preferable
- Lossless compression is less efficient on uncalibrated data

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Error Resilience Experiment

- A scan element corresponds to the set of image lines that are compressed as a unit and output directly to the downlink
  - It may be defined as a file (in image space) or a set of precincts (in wavelet space)
- Assume all wavelet coefficients for a scan element are formatted into a single communications packet
- Assume the whole packet is discarded if it contains any corrupted data
  - Simulate this by setting all wavelet coefficients in the packet to zero
- Decompress the file as usual and determine extent of damage in the image

Example of Packet Loss

This is a SPOT image of Los Angeles, compressed to 2.0 bpp, in which one 8-line scan element has been lost

JPEG 2000 Error Resilience Features

- JPEG 2000 entropy coding is based on context-based arithmetic coding
  - Encoder & decoder must maintain synchronization
- The smallest independent coding unit is the code block
  - In the default mode, re-sychronization occurs after each code block
- Three coding passes are used for each code block
  - In the “error resilient mode”, the decoder can detect an error at the end of each coding pass
  - A corrupt coding pass can be discarded (as well as subsequent coding passes for that code block)
- Data can be recovered from a corrupted packet and artifacts can be minimized
- Header information must be protected

Example of Using Error Resilience Features

E.R. Off

E.R. On

SPOT image of Los Angeles, compressed to 1.0 bpp.
Subjected to a bit error rate of 10^{-4} and decompressed.

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Preliminary Conclusions on Error Resilience

- Damage from packet loss is confined to a few lines above and below the affected scan element
- The effect would be similar for any wavelet-based algorithm
- JPEG 2000 error resilience features may make it possible to recover some uncorrupted data from a damaged packet

Task-Oriented Experiments

- Work with scientists using HSI data
  - Test a range of compression ratios (8 to 256)
  - Determine acceptable compression ratio for scientific applications
- Canadian Forest Service (D. Goodenough)
  - Forest chemistry, classification, species recognition
  - Hyperion data received and compressed
  - Lossless compression ratio is 2.4/1
  - Results of application testing to be received shortly

Task-Oriented Experiments (continued)

- Soil, Water & Environmental Science Department, University of Arizona (A. Huete)
  - Classification based on image statistics, vegetation indices
  - Hyperion data received and compressed
  - Awaiting design of application test
  - MODIS data also of interest

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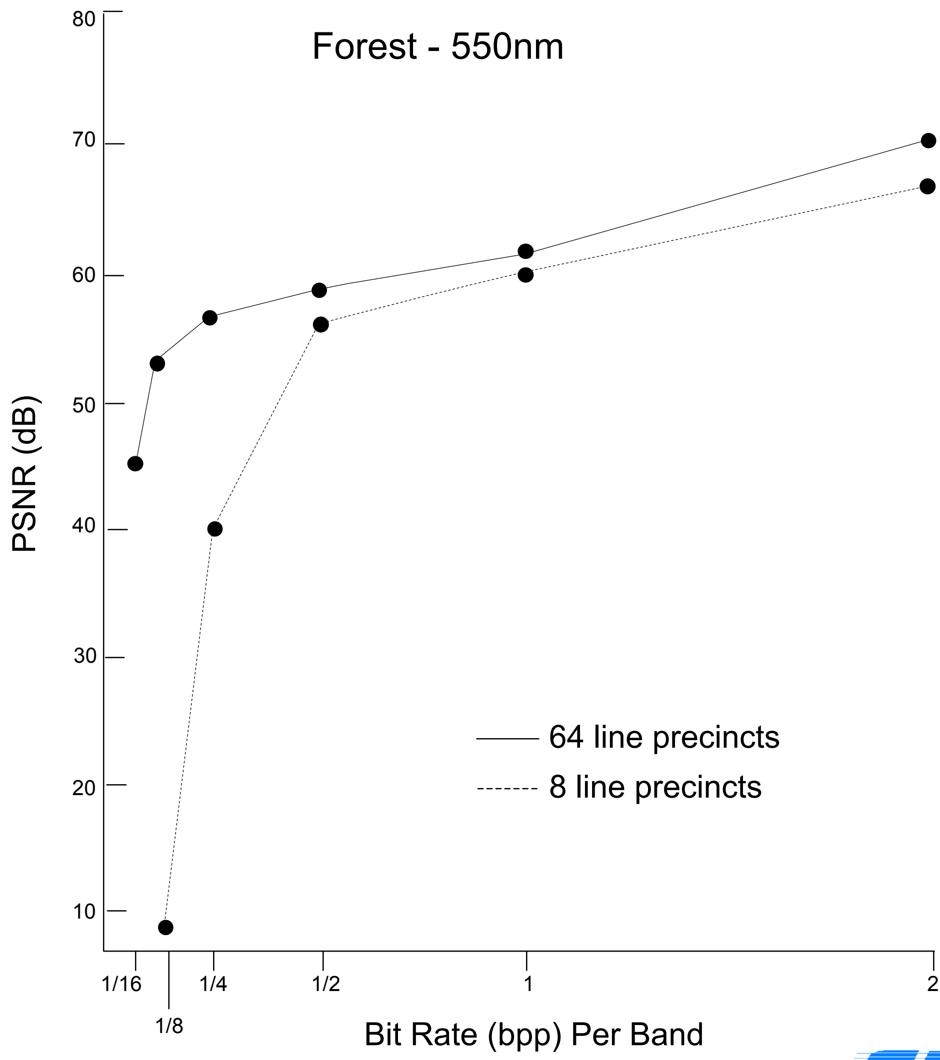
Example of Hyperion Compression

Bands
115, 35, 23

Forest



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Conclusion

- This project has demonstrated that JPEG 2000 offers many advantages for the compression of Earth Science data
- In scan-based mode, JPEG 2000 is suitable for on-board use and meets speed and memory requirements
- The next step should be flight software or flight-worthy hardware